

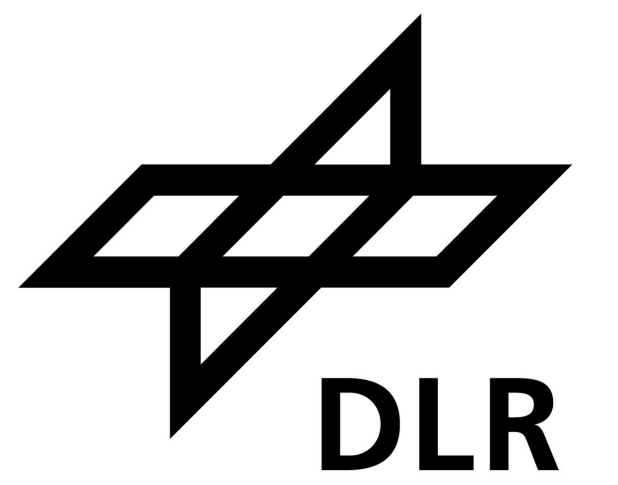
# Improved Characterization of Planetary Wave Evolution Following Polar Stratospheric Vortex Anomalies Using Large Ensemble Simulations

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## 1 Motivation

- **Sudden stratospheric warmings (SSWs)** are observed to be followed by persistent tropospheric circulation anomalies, with an increased likelihood of negative Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) phases (Baldwin & Dunkerton, 2001).
- **Suppressed upward wave activity flux:** after SSWs, upward planetary wave activity flux remains anomalously weak throughout the stratosphere–troposphere column for several weeks (Hitchcock & Simpson, 2014).
- **Suggested pathway:** these planetary wave changes may play a role in communicating the stratospheric signal to the troposphere.
- **Knowledge gap:** the mechanisms behind the reduced tropospheric planetary wave activity flux after SSWs remain incompletely understood.

### Our approach

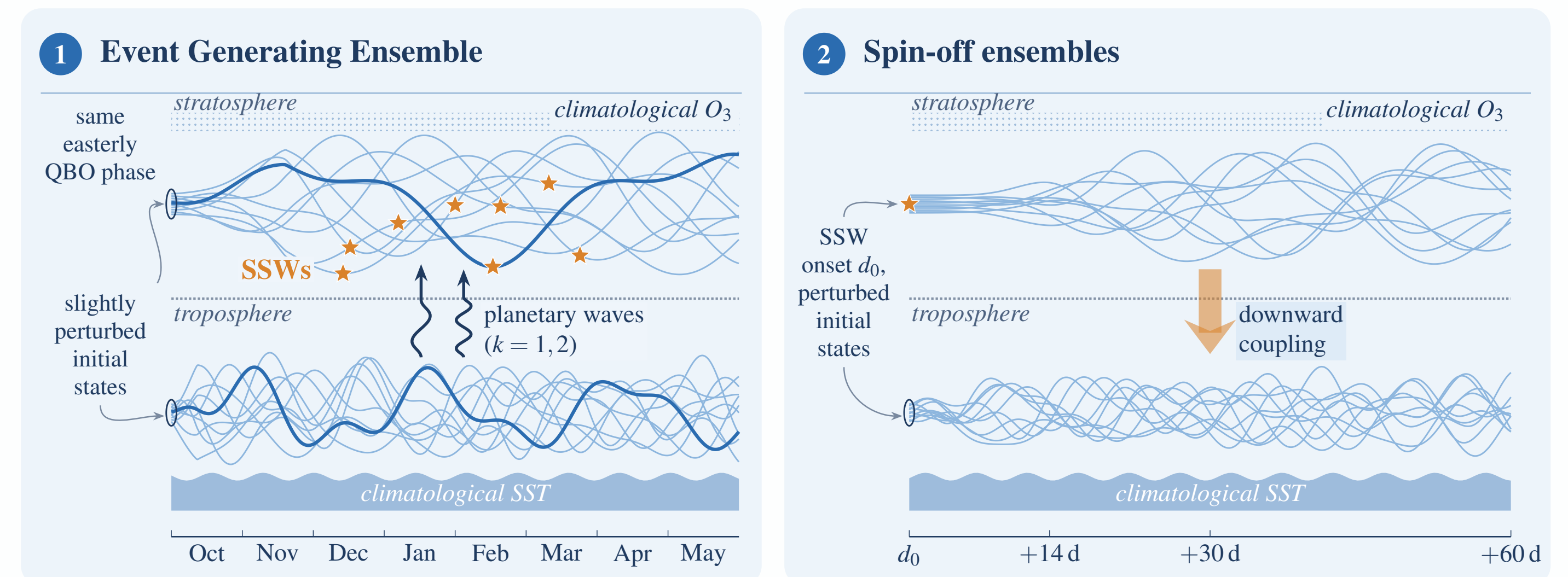
- Post-SSW evolution of wave 1 ( $k = 1$ ) and wave 2 ( $k = 2$ ), analyzed separately, in terms of the vertical structure of amplitude, phase and wave activity flux.
- Large ensembles of dedicated ICON simulations.

## 2 Model setup

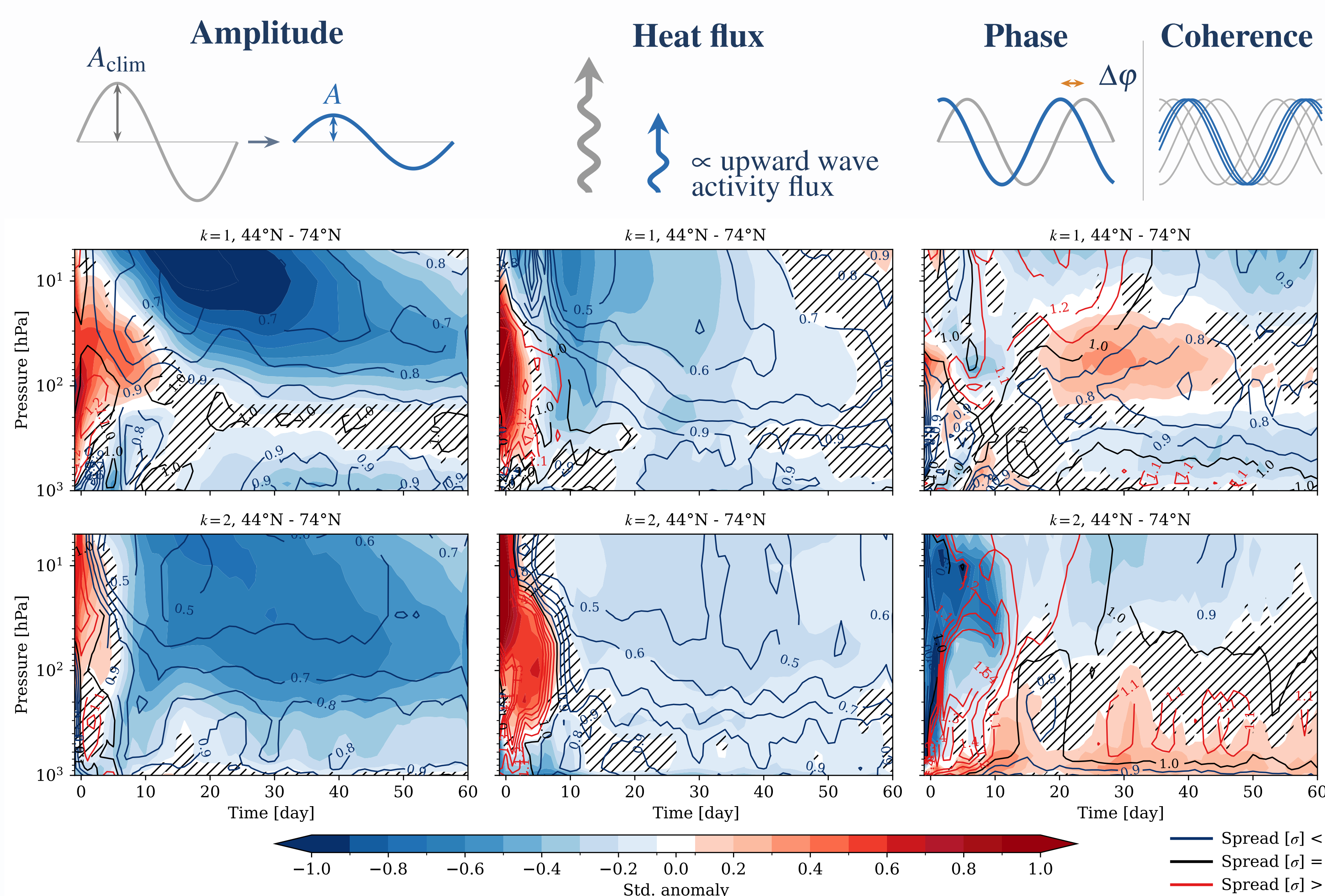
**Why ensembles?** In a single realization, the tropospheric response to an SSW is masked by internal variability. Large ensembles average out this noise and isolate the response.

**Approach:** ICON (global NWP model) in two steps (Loeffel et al., 2026):

- 1 **Event Generating Ensemble:** 120 winters, fixed boundary conditions → 72 SSWs.
- 2 **Spin-off ensembles:** 18 SSWs restarted at onset, 40 members each:
  - event-specific response for each SSW
  - 720 post-SSW evolutions for robust statistics



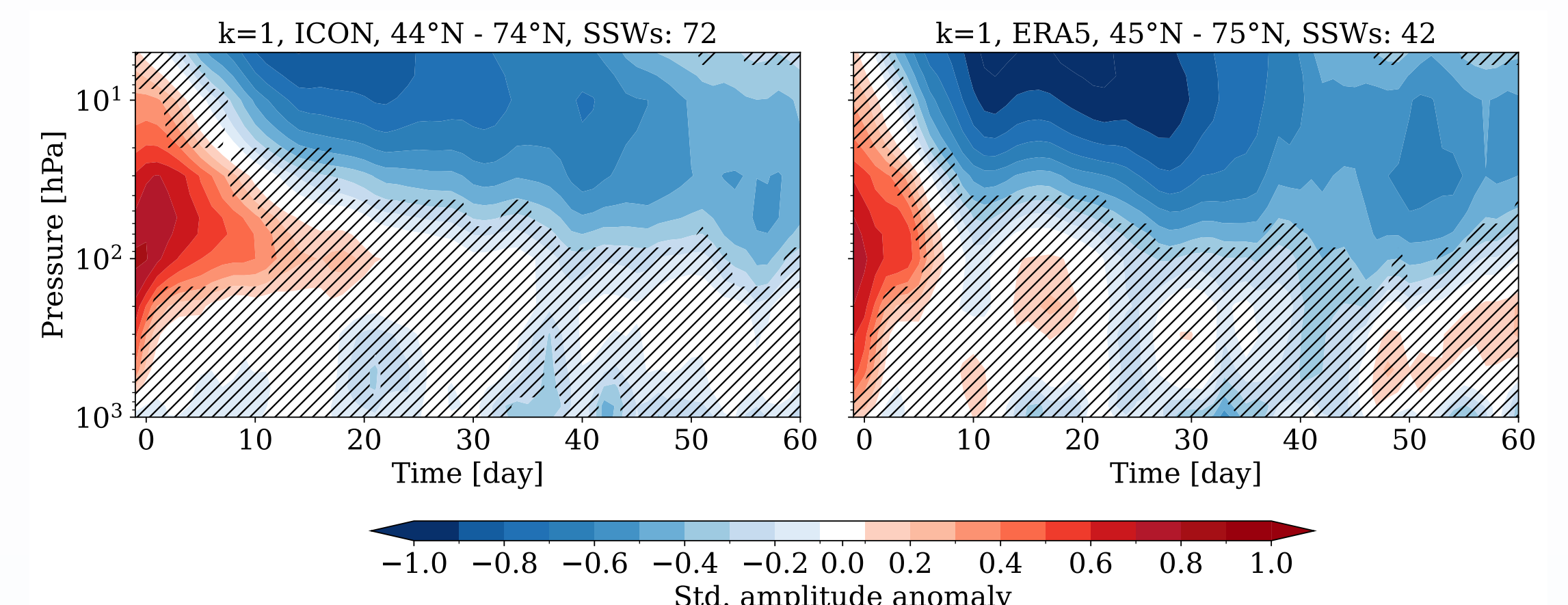
## 4 Post-SSW time evolution (720 spin-off members)



**Composite shows:**

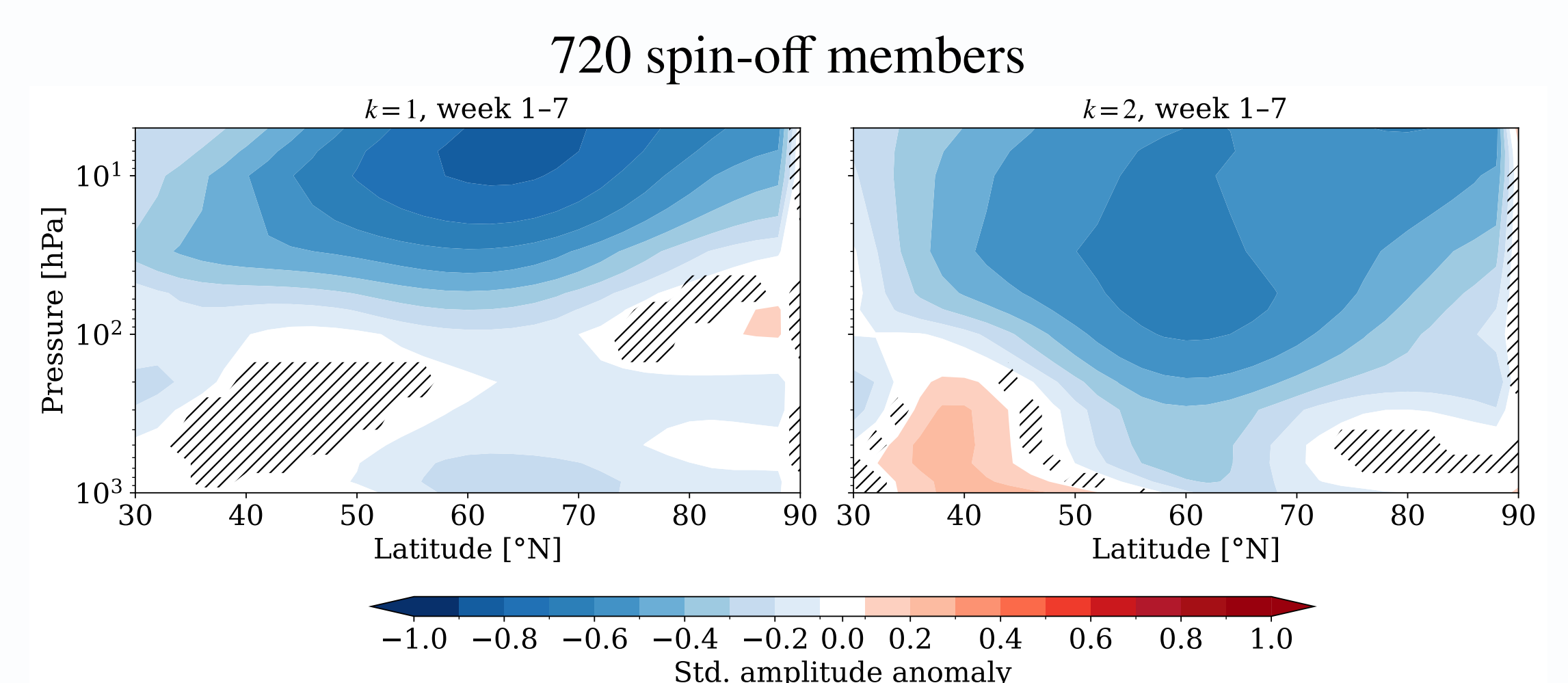
- Statistically significant wave response to SSWs in stratosphere and troposphere.
- Its vertical structure differs between wave 1 and wave 2.

## 3 Event Generating Ensemble vs. ERA5



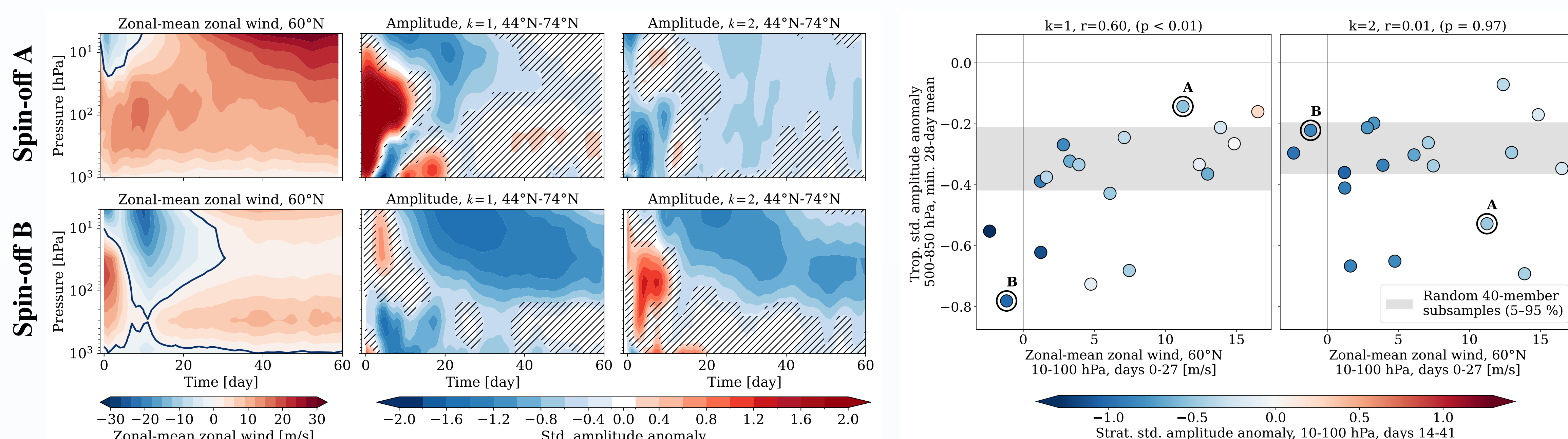
Consistent post-SSW wave evolution, e.g. wave-1 amplitude.

## 5 Latitudinal structure of amplitude response



Differences between wave 1 and 2, especially in the troposphere.

## 6 Event-to-event differences between individual SSWs (18 spin-off ensembles)



### Key points

- Large case-to-case variability of the wave response.
- Relationships of the wave response to basic-state variables, e.g. the zonal-mean zonal wind, differ between wave 1 and wave 2.

### Future directions

Mechanistic understanding of how the basic state shapes the wave-1 and wave-2 responses.

### References

- Baldwin, M. P., and T. J. Dunkerton, 2001: Stratospheric harbingers of anomalous weather regimes. *Science*, **294**, 581–584.
- Hitchcock, P., and I. R. Simpson, 2014: The downward influence of stratospheric sudden warmings. *J. Atmos. Sci.*, **71**, 3856–3876.
- Loeffel, S., et al., 2026: Quantifying the tropospheric response to individual sudden stratospheric warmings revealed by an ensemble simulation strategy. *Weather Clim. Dyn.*, **7**, 895–913.